Interdisciplinary technology studies, from a Dutch perspective

Interdisciplinary Technology Studies From a Dutch Perspective

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This is a hybrid paper. It is as hybrid indeed as the symposium itself which aims, first, at discussing the experiences that several European projects have with interdisciplinary research in the field of science and technology studies and, second, at discussing the interdisciplinary study of large technological systems in particular.
The first objective pursued in this paper is to give a brief review of the 'Dutch scene' in science and technology studies. This is done in Part I where I will sketch the recent history of this field of research in the Netherlands. In an appendix at the end of this paper, two Dutch programs will be described more in detail. The second objective of this paper is to give in Part II an account of recent developments in the interdisciplinary studies of technology. One important element in this is the systems approach which plays a central role in the second part of this symposium. The two other elements are the actor network approach and the social constructivist approach. Only the latter will be described in this paper, since the first two approaches are discussed in the contributions by Bowker, Hughes, and Law to this symposium. At the end of Part II it will be argued that these three approaches, coming from different disciplinary backgrounds, can constitute fruitfully an interdisciplinary research program. By enhancing their strength mutually rather than quarreling about differences, they exemplify the benefits of interdisciplinary research.

Part I
Development of Science and Technology Studies in the Netherlands

The development of the science and technology study centres as they are presently in operation in the Netherlands can be described as having occurred in three stages – (1) the emergence of science, technology and society (STS) groups in the late 1960s and early 1970s, (2) the increasing focus on the developmental processes of science and technology in the late 1970s, and (3) the fully-fledged science and technology dynamics in the 1980s.

The first stage (the establishment of STS groups at many science and engineering departments of Dutch universities) was a result of the radical student movement in the late 1960s. Of course, it was also part of a much broader concern related to issues such as environmental pollution, the arms race and the consumption society. In this first stage, the main issue addressed in STS teaching and research was the impact of technology and science on society. If we may caricature the concern of science studies in the previous period as 'science is a cow; the task of our research is to develop ways to get as much milk out of her as possible', then the caricature of the STS concern in the early 1970s is 'the science-technology complex is a bull running through a porcelain society; the task of our research is to develop means to get the beast under control'. Besides these questions of impact on society and control of science and technology, the other important issue was the 'social responsibility of the scientist and engineer'. Under that aegis many STS courses were introduced at Dutch universities. An ethical code for engineers was discussed and some students swore solemn oaths (to employ their knowledge only for the benefit of mankind) at the official occasion of receiving their engineering degree. In this period, the well-known Dutch 'science shops' were established at most universities.

In the second stage, the STS community felt a growing dissatisfaction because the action-oriented research did not develop beyond the stage of 'symptom-fighting' and did not result in a more fundamental understanding of the character of science and technology. In this period the studies by Thomas Kuhn[1] and the work by the German 'Starnberg' group[2] had an important impact on the Dutch STS society. Initially mainly within the realm of philosophical studies of science, the research because more focused on the process of science development. This culminated in 1979 in a symposium on the internalist/externalist debate in the interpretation of science development.

Then, in the third stage, the need for empirical research as a basis for understanding science and technology development was recognized. First sociological and more recently historical studies were designed to provide this basis. Theoretically, the distinction between internalist and externalist approaches, so central during the second stage, was transcended and a more integrated approach emerged. Now all issues mentioned previously are on the agenda, but in an intimate relationship. Impact of technology and science on society is the mirror-image twin of the social shaping of science and technology. The social responsibility of scientists is studied in relation to questions of social dynamics and the constraints an individual scientist experiences within the scientific community. Technical questions of technology assessment are related to studies of long-term development of technology.

Institutional Developments in the Netherlands

In disciplinary terms, the Dutch science and technology studies community originally was built around scientists and engineers. They started the STS courses and research in the first stage and they developed the philosophical and empirical approaches in the second and third stage. Only now, in the third stage, a growing number of social scientists gets involved in science and technology studies: historians, sociologists, economists and also philosophers. This makes the research truly interdisciplinary, with all problems related to that. One problem is, for example, to get funding for these interdisciplinary projects while the refereeing bodies are still organized along the lines of the 'old' disciplines.
Institutionaly, there has been some concentration and specialization. Although most science and engineering departments still have a little STS groups (often only one person) for teaching purposes, and although most science shops are flourishing, the research in this field is concentrated in the Universities of Amsterdam (UvA), Groningen, Twente (in Enschede), Utrecht and Limburg (in Maastricht) and the Free University (FU, also in Amsterdam). The Universities of Amsterdam, Groningen, Limburg and Twente have established a graduate school for science and technology studies. Technology studies are concentrated in the triangle Amsterdam (UvA), Twente, Limburg. Technology assessment is to be found primarily in Amsterdam (FU), Utrecht, Twente. A focus on medical science and technology can be located in Amsterdam (UvA), Groningen, Limburg. Military technology is studied in Amsterdam (FU) and Twente. In addition to these, the Technical University of Eindhoven has an important centre for the history of technology and a group based at the University of Leiden is specializing in quantitative, scientometric studies of science.
At one place, the University of Twente, a Master's degree in science studies is offered. In an appendix to this paper, I will sketch this program more fully. At the University of Limburg plans for an interdisciplinary program, also offering a Master's degree but not exclusively focussing on science studies, are in their final stage of development – some of the basic ideas of this program are discussed in a second appendix.

Part II
Background of Recent Developments in Technology Studies[3]

There is a very large amount of writing which falls under the rubric of 'technology studies'. It is convenient to divide the literature into three parts – innovation studies, history of technology and sociology of technology. I will briefly discuss each set of literature in turn.

Innovation studies

Most innovation studies have been carried out by economists with a view towards finding the conditions for success in innovation. Factors researched include various aspects of the innovating firm (for example, size of R & D effort, management strength and marketing capability) along with macro-economic factors pertaining to the economy as a whole. This literature is in some ways reminiscent of the early 'black box' days in the sociology of science.[4] Before sociologists addressed the content of science, scientific knowledge was treated like a 'black box' and, for the purpose of such studies, scientists might as well have produced meat pies. Similarly, in the economic analysis of technological innovation everything is included that might be expected to influence innovation, except any discussion of the technology itself.

As Layton notes: "What is needed is an understanding of technology from inside, both as a body of knowledge and as a social system. Instead, technology is often treated as a 'black box' whose contents and behaviour may be assumed to be common knowledge".[5] Only recently economists have started to look into this black box.[6]

History of Technology

The criticism of ignoring the technological content of innovations cannot be levelled at the history of technology where there are many finely crafted studies of the development of particular technologies. However, for the purposes of a sociology of technology, work in the history of technology presents two kinds of problems. Firstly, the problem of descriptive historiography is endemic in this field. Very few scholars (but there are some notable exceptions – see below) seem concerned to generalize beyond historical instances and it is difficult to discern any overall patterns upon which to build a theory of technology. In other words, many historians of technology can be criticized for never looking *outside* the black box of the piece of technology they are studying.

The other problem presented by most of the historical material concerns the asymmetrical focus of the analysis. For example, it has been claimed that in 25 volumes of *Technology and Culture* only 9 articles were devoted to the study of failed technological innovations.[7] This is one of the sources of the implicit adoption of a linear structure of technological development, which suggests that "... the whole history of technological development had followed an orderly or rational path, as though today's world was the precise goal toward which all decisions, made since the beginning of history, were consciously directed"[8].

This preference for successful innovations seems to be conducive to the implicit adoption of precisely the success of an artefact as an explanatory ground for its

development. In many cases historians of technology seem content to rely on the manifest success of the artefact as evidence that there is no further explanatory work to be done. An example may illustrate this point. Many histories of synthetic plastics start by describing the technically sweet characteristics of Bakelite. Then these features are often used implicitly to position Bakelite at the starting point of the glorious development of the synthetic plastics field:
"God said: 'Let Baekeland be' and all was plastics"[9]!
However, a more detailed study of the developments of plastic and varnish chemistry following the publication of the Bakelite process in 1909[10] shows that Bakelite was at first hardly recognized as the marvellous synthetic resin which it later proved to be[11]. And this situation did not change very much for some ten years. During the First World War the market prospects for synthetic plastics actually grew worse. However, the dumping of war supplies of phenol (also used in the manufacture of Bakelite) in 1918[12] changed all this, and made it possible to keep the price sufficiently low to compete with (semi-)natural resins, such as celluloid. One can speculate over whether Bakelite would have acquired its prominence if it has not profited from that phenol dumping. In any case it is clear that a historical account founded upon the retrospective success of the artefact leaves much untold.
Especially in the American history of technology there is an emerging interest in more sociological perspectives on technology. Also a growing number of theoretical themes upon which research is focussed can be identified.[13] For example, the systems approach towards technology[14] and the effect of labour relations on technological development[15] seem to herald departures from the 'old' history of technology. At the 1986 and 1987 annual meetings of the Society for the History of Technology special sessions were devoted to an integrated sociological-historical discussion of technology.

Sociology of technology

The final body of work to be discussed is that which might be described as 'sociology of technology'.[16] There have been some limited attempts before the 1980s to launch a sociology of technology using ideas developed in the history and sociology of science. I refer in particular to studies by, for example, Johnston[17] and Dosi[18] who advocate the description of technological knowledge in terms of Kuhnian paradigms[19]. Such approaches certainly appeared to be more promising than standard descriptive historiography, but it was not clear that technological artefacts could be understood as social constructs. For example, neither Johnston nor Dosi considered explicitly the need for a symmetrical sociological explanation which treats successful and failed artefacts in an equiv-

alent way. Indeed, by locating their discussion at the level of technological paradigms it was not clear how the artefacts themselves were to be approached. As neither author has produced an empirical study using these Kuhnian ideas it is difficult to evaluate how the Kuhnian terms may be operationalized. Again, the situation may be summarized by the observation that the early sociologists of technology did not look into the black box of technology.
Recently this situation has been starting to change. Within the three disciplines, developments have started to counter the previously described limitations. Economic research is increasingly taking into account the content of the technological black box and this applies to sociological studies as well. Historical work is devoting more attention to model building and theoretical and sociological issues. Moreover, these disciplinary developments are amplifying each other in an interdisciplinary collaboration as well.

The Social Construction of Technological Systems and Actor Networks: An Interdisciplinary Research Program for New Technology Studies

In 1984 an international workshop was held which brought together some thirty historians, sociologists and philosophers of technology – some of them having a background in engineering or science. The workshop was located in *De Boerderij* ('The Farm') on the campus of the Twente University of Technology. As has been noted elsewhere[20], the differences in historical, sociologiocal and philosophical approaches, and the idiosyncrasies of six different nationalities meant it could have been a dialogue of the deaf. However, quite the contrary happened. All the participants appeared to have come, not only to talk, but also to listen. The workshop was marked by an open and sympathetic intellectual atmosphere and discussions of a genuinely interdisciplinary nature occurred. More specifically, a high tolerance was shown for different and sometimes even incompatible concepts and approaches. If a new idea was not found to be immediately convincing, it was not knocked down but discussed critically and then 'carried along' to later sessions while we suspended final judgement. New strands of discussion emerged, linking different papers together on a level which no one had envisaged in advance.
It can safely be stated now, that a new field of interdisciplinary technology studies is emerging. The hallmarks of this field are set out in the volume based on the 1984 workshop.[21] Recent publications and conference sessions have further explicated the goals, themes and perspectives.[22]
At this moment, three different approaches can be identified in this new field – the systems approach, the actor network approach and the social constructivist

approach. Although the fruitful heterogeneity of the field is much broader than the sum of these approaches, it can be argued that they together constitute a kind of informal interdisciplinary research program. I will describe these approaches very briefly, devoting most space to the social constructivist approach since the other two approaches will be taken care of by Hughes, Bowker and Law in their respective contributions to this symposium.

The Systems Approach

The systems approach, in this context developed by Thomas P. Hughes, is aiming at an analysis of technological systems.[23] These technological systems are constituted by a complex set of problem solving elements. They are socially constructed on the one hand, but are shaping society on the other hand as well. Examples of components in a technological system are: physical artefacts such as generators, transformers and electricity cables; organizations such as electric utilities, manufacturers of electrical equipment and investment banks; scientific elements such as education programs, publications and patents; and even things like the national legal system and coal mines.
A component of a technological system is continually interacting with other components of that system. If one component is changed, this has implications for the other components. Thus a change in the average power consumption of electrical appliances leads to changes in the transformers and the generators. All components are interconnected and are influencing each other. In this way, the distinction between technical and social vanishes. In an artefact such as Edison's lamp, the whole spectrum of technical, social and political circumstances in which the system builders of those electricity distribution networks were working is built-in.
Technological systems develop according to certain patterns. Hughes describes an evolving technological system by using, among others, the concepts 'reverse salient' and 'critical problem'. He observes how technological systems gain momentum when they grow and acquire strength. This concept 'technological momentum' enables Hughes to analyse the seemingly autonomous character of technological systems.

Actor Network Approach

The actor network approach is developed by Callon, Latour and Law.[24] Like the systems approach, elements of quite different nature are treated on an equal footing as components in the network: accumulators, engineers, electrons, ministries, lead, research institutions and petrol. This approach is related to a quantitative research instrument, 'co-word analysis'.[25] This instrument allows you to make charts of communication networks, from which information can be gained about actor networks.

A central concept in the actor network approach is 'translation'. Components of an actor network are not fixed, unchanging entities. They evolve permanently, influenced by changes in other components and the network itself. Elements need to be 'translated' to be effectively a component of the actor network. Callon has used his case study of the French electric vehicle to illustrate these processes. Hughes' 'system builder' here is called a 'heterogeneous engineer', who is continuously translating elements to maintain a stable and durable actor network.

Social Constructivist Approach[26]

The Social Construction of Technology (SCOT) approach focusses on the meanings attributed to artefacts by various relevant social groups. Artefacts are understood as being constituted by the social interactions within and between those social groups – artefacts are being built-up from the meanings attributed to them. For the description and analysis of the developmental process of an artefact, we take for methodological reasons a rather radical *esse est percipi* view.

In SCOT the developmental process of a technological artefact is described as an alternation of variation and selection. This results in a 'multi-directional' model which can be seen as contrasting with the linear models which have been used explicitly in many innovation studies, and implicitly in most of the history of technology. To have such a multi-directional view of the developmental process of technological artefacts is a necessary condition for giving a symmetrical account of technology. It is only by retrospective distortion that a quasi-linear development emerges. In this representation the so-called 'safety ordinaries' ('Xtraordinary', 1878; 'Facile', 1879; and 'Club Safety', 1885) only figure as amusing aberrations which need not to be taken seriously. Such a retrospective description can be challenged by looking at the actual situation in the 1880s. Some of the 'safety ordinaries' were produced commercially, whilst Lawson's 'Bicyclette', which seems to play an important role in the linear model of Whig history, proved to be a commercial failure.

If a multi-directional model is adopted instead, it is possible to ask why some of the variants 'die', whereas others 'survive'. To illuminate this 'selection'-part of the developmental processes, we focus on the problems and solutions presented by each artefact at particular moments. The rationale for concentrating upon problems and solutions is the same as the reason for focussing upon scientific controversies within recent studies in the sociology of scientific knowledge, especially in the Empirical Program of Relativism (EPOR) – one can expect to bring out more clearly the interpretative flexibility (see below) of technological artefacts in this way.

In deciding which problems are relevant, a crucial role is played by the social groups concerned with the artefact and by the meanings which those groups attribute to the artefact: a problem is only defined as such, when there is a social group for which it constitutes a 'problem'. The use of the concept 'relevant social group' is rather straightforward. The term is used to denote institutions and organizations such as the military or some specific industrial company, as well as organized or unorganized groups of individuals. The key requirement is that all members of a certain social group share the same set of meanings, attached to a specific artefact. In deciding which social groups are relevant, the question we first have to consider is whether the artefact has any meaning at all for the members of the social group under investigation. Obviously the social group of 'consumers' or 'users' of the artefact fulfills this requirement. But also less obvious social groups may need to be included. In the case of the bicycle, for example, one needs to mention the 'anti-cyclists'. Their actions ranged from derisive cheers to more destructive methods. For example, Rev. L. Meadows White described such resistance to the bicycle in his book, *A Photographic Tour on Wheels:*

"... but when to words are added deeds, and stones are thrown, sticks thrust into the wheels, or caps hurled into the machinery, the picture has a different aspect. All the above in certain districts are of common occurrence, and have all happened to me, especially when passing through a village just after school is closed"[27].

Clearly, for the anti-cyclists the artefact 'bicycle' had taken on meaning!

Another question we need to address, is whether a provisionally defined social group is homogeneous with respect to the meanings given to the artefact; or else, is it more effective to describe the developmental process by dividing a rather heterogeneous group into several different social groups? Thus, within the group of cycle-users we discern a seperate social group of women cyclists. During the days of the high-wheeled 'Ordinary', women were not supposed to mount a bicycle. For instance, in a magazine advice column (1885) it is proclaimed in reply to a letter from a young lady: "The mere fact of riding a bicycle is not in itself sinful, and if it is the only mean of reaching the church on a Sunday, it may be excusable"[28].

Tricycles were the permitted machines for women. But engineers and producers anticipated the importance of women as potential bicyclists. In a review of the annual Stanley Exhibition of Cycles in 1890 the author observes: "From the number of safeties adapted for the use of ladies, it seems as if bicycling was becoming popular with the weaker sex, and we are not surprised at it, considering the saving of power derived from the use of a machine having only one slack"[29].

Thus, in the case of the bicycle, some parts of the developmental process can be explained better by including a separate social group of feminine cycle-users. Certainly, this need not to be the same in other cases. For instance, I do not expect it would be useful to discern a separate social group of women users of, say, transistors.

Generally, the actors will identify the relevant social groups themselves by refering explicitly to them.[30] After the identification of the relevant social groups, they are described in more detail. Although the only defining property is some homogeneous meaning attributed to a certain artefact, the intention is not just to retreat to worn-out, general statements about 'consumers' and 'producers'. We need to have a detailed description of the relevant social groups in order better to define the function of the artefact with respect to each group. Without this, one could not hope to be able to give any explanation of the developmental process. For example, the social group of cyclists riding the high-wheeled Ordinary, consisted of 'young men of means and nerve: they might be professional men, clerks, schoolmasters or dons'. For this social group the function of the bicycle was primarily for sport.

Let us now return to the exposition of the descriptional SCOT model. Having identified the relevant social groups for a certain artefact, we are especially interested in the problems each groups has with respect to that artefact. Around each problem, several variants of solution can be identified. This way of describing the developmental process brings out clearly all kinds of conflicts: conflicting technical requirements by different social groups (e.g. the 'speed'-requirement and the 'safety'-requirement), conflicting solutions to the same problem (e.g. the Safety Low Wheelers and the Safety Ordinaries – this type of conflict often results in patent litigation), and moral conflicts (e.g. women wearing skirts or trousers on a High Wheeler). Within this scheme, various solutions for these conflicts and problems are possible – not only technological, but also judicial, or even moral (e.g. changing attitudes towards women wearing trousers).

Following the development process in this way, we see growing and diminishing degrees of stabilization of the different artefacts. In principle the degree of stabilization is different amongst different social groups. By using the concept of stabilization, the 'invention' of the Safety Bicycle is seen not as an isolated event (1884), but dissolves into a nineteen-year process (1879–1898). For example, at the beginning of this period the relevant groups did not see the safety bicycle, but a wide range of bi- and tricycles and among those a rather ugly crocodile-like

bicycle with a relatively low frontwheel and rear chain drive (Lawson's Bicyclette). By the end of the period the word 'safety bicycle' denoted a low-wheeled bicycle with rear chain drive, diamond frame and air tyres. As a result of the stabilization of the artefact after 1898, one did not need to specify these details: they were taken for granted as the essential 'ingredients' of the safety bicycle.
A direct consequence of the description of artefacts as being constituted by meanings attributed by different social groups is that in such a description different artefacts will be staged, where 'really' there is only one. This 'interpretative flexibility' of artefacts can be demonstrated by the sociologist or historian of technology in various ways. For example, one could interview technologists who are engaged in a contemporary technological controversy. Thus we can imagine that if interviews had been carried out in 1890 with the cycle engineers, we would have been able to show the interpretative flexibility of the artefact 'air tyre'. For some this artefact had the meaning of a solution to the vibration problem of small-wheeled vehicles: The air tyre was "devised with a view to afford increased facilities for the passage of wheeled vehicles – chiefly of the lighter class such for instance as velocipedes, invalid chairs, ambulances – over roadways and paths, especially when these latter are of rough or uneven character"[31].
For others, the air tyre took on a meaning as a way of going faster (this will be outlined in more detail below). For yet another group of engineers it had the meaning of an ugly looking way of making the low-wheeler yet more unsafe (because of side-slipping) than it already was. For instance, the following comment describing The Stanley Exhibition of Cycles, is revealing:
"The most conspicuous innovation in the cycle construction is the use of pneumatic tyres. These tyres are hollow, about 2 in. diameter, and are inflated by the use of a small air pump. They are said to afford most luxurious riding, the roughest macadam and cobbles being reduced to the smoothest asphalt. Not having had the opportunity of testing these tyres, we are unable to speak of them from practical experience; but looking at them from a theoretical point of view, we opine that considerable difficulty will be experienced in keeping the tyres thoroughly inflated. Air under pressure is a troublesome thing to deal with. From the reports of those who have used these tyres, it seems that they are prone to slip on muddy roads. If this is so, we fear their use on rear-driving safeties – which are all more or less addicted to side-slipping – is out of the question, as any improvement in this line should be to prevent side slip and not to increase it. Apart from these defects, the appearance of the tyres destroys the symmetry and graceful appearance of a cycle, and this alone is, we think sufficient to prevent their coming into general use"[32].
Thus, the interpretative flexibility of the air tyre is demonstrated by showing that effectively it comprised at least three different artefacts.

We take the interpretative flexibility to show the existence of 'really' different artefacts, because the different social groups have radically different interpretations of one technological artefact. This difference is called 'radical', because the content of the artefact apparently is involved. This was shown with the previous example of the development of the safety bicycle. Another example is provided by the variations within the high-wheeler. The high-wheeler's meaning as a virile high-speed bicycle led to the development of larger front wheels – for, with a fixed angular velocity, the only way of getting a higher translational velocity over the ground was by enlarging the radius. One of the last bicycles resulting from this strand of development was the Rudge Ordinary of 1892 with a 56-inch wheel and air tyre. The groups of women and of elderly men gave quite another meaning to the high-wheeler. For them the most important characteristic was its lack of safety:

"Owing to the disparity in wheel diameters and the small weight of the backbone and trailing wheel, also to the rider's position practically over the centre of the wheel, if the large front wheel hit a brick or large stone on the road, and the rider was unprepared, the sudden check to the wheel usually threw him over the handlebar. For this reason the machine was regarded as dangerous, and however enthusiastic one may have been about the ordinary – and I was an enthusiastic rider of it once – there is no denying that it was only possible for comparatively young and athletic men"[33].

This meaning gave rise to lowering the front wheel, moving back the saddle, and giving the front fork a less upright position. Via another chain of problems and solutions, this resulted in artefacts such as Lawson's Bicyclette (1879) and the Xtraordinary (1878). Thus, there was not one high-wheeler but there were two – there was the *macho* machine, leading to new designs of bicycles with even higher front wheels, and there was the *unsafe* machine, leading to new designs of bicycle with lower frontwheels, saddles moved backwards, or reversed order of small and high wheel like in the American 'Star' bicycle. Thus, the interpretative flexibility of the artefact Penny-farthing is materialized in quite different design lines.

Having demonstrated the interpretative flexibility of an artefact, the subsequent task of the sociologist or historian of technology is to describe and explain how in the end only one artefact stabilized. I will use the example of the air tyre again. As shown previously, for most of the engineers it had the meaning of a theoretical and practical monstrosity. For the general public, in the beginning it had the meaning of an aesthetically awful accessary:

"... messenger boys guffawed at the sausage tyre, factory ladies squirmed with merriment, while even sober citizens were sadly moved to mirth at a comicality obviously designed solely to lighten the gloom of their daily routine"[34].

For Dunlop and the other protagonists of the air tyre, originally it had the meaning of a solution to the vibration problem. However, the group of sporting cyclists riding their high-wheelers did not accept that to be a problem at all. Vibration presented a problem to the (potential) users of the low-wheeled bicycle only. Three important social groups were therefore opposed to the air tyre. But then the air tyre was mounted on a racing bicycle. When, for the first time, the tyre was used at the racing track, its entry was hailed with derisive laughter. This was, however, quickly silenced by the high speed achieved and there was only astonishment left when it outpaced all rivals. Very soon handicappers had to give racing cyclists on high wheelers a considerable start if riders on air-tyred low wheelers were entered. After a short period no racer of any pretensions troubled to compete on anything else.

What had happened? With respect to two important groups, the sporting cyclists and the general public, stabilization had been reached – but not by convincing those two groups of the feasibility of the air tyre in its meaning as an antivibration device. One can say, we think, that the meaning of the air tyre was translated to constitute a solution to quite another problem: the problem of 'how to go as fast as possible'. And thus, by re-defining the key problem with respect to which the artefact should have the meaning of a solution, stabilization was reached for two of the relevant social groups. The story of how the third group, the engineers, came to accept the air tyre is another story and need not to be told here. Of course, there is nothing natural or logically necessary about this form of stabilization. It could be argued that speed is not the most important characteristic of the bicycle or that existing cycle races were not appropriate tests of a cycle's 'real' speed (after all, the idealized world of the race track may not match everyday road conditions any more than the formula-one racing car bears upon the performance requirements of the average family saloon). Still, bicycle races have played an important role in the development of the bicycle and since racing can be viewed as a specific form of testing, this observation is very much in line with Constant's plea to pay more attention to testing procedures in studying technology.[35]

The SCOT descriptional model I have outlined here is primarily a heuristical device, aimed at describing different cases in such a uniform way that they can be used as a basis for comparative analysis and generalization. Thus the SCOT approach, like the other two approaches mentioned previously, comprises detailed empirical analyses of the 'content' of various technological artefacts and systems as well as their environment. This 'thick description' results in a wealth of detailed information about the technical, social, economic and political aspects of technology. In order to contribute to our overall understanding of technology, however, this wealth of information needs to be simplified and structured – thus creating order out of the chaos of data. Of course, the construction of models or 'middle-range' theories necessarily over-simplifies the rich texture of each case but this need not worry us, as long as it is recognized and thus made amenable to critical discussion. A model that incorporates every aspect of the case it deals with would fail to serve is function, being no more than a re-creation or re-description of the original case. In SCOT the concept 'technological frame' refers to the ways in which relevant social groups attribute various meanings to an artefact. The concept 'inclusion' is introduced to account for the oberservation that there are varying degrees of interaction within any one technological frame. The social processes underpinning the social construction of artefacts are explained in terms of the differing degrees of inclusion of actors within different technological frames.[36]

Benefits of Integration of the three Approaches into one Interdisciplinary Research Program

The three approaches described in the previous section have more similarities than differences. For example, they all respect the 'seamless web' of technology and society, they oppose technological determinism, they use 'thick description' as a basis for theoretical understanding, and they avoid using the 'working well' of an artefact as *explanans* (instead, what constitutes a 'working' artefact is what needs to be explained). However, more important than the direct similarities seem to be the complementary features of the three approaches. One example is MacKenzie's analysis of the socially constructed character of reverse salients.[37] Another example is the micro/macro problem which I will discuss briefly.

The micro/macro problem is the question, how to relate the local events on the level of individual engineers, artefacts and users to the processes on the level of technical disciplines, engineering communities, industrial organizations and society. The three approaches each have their own perspective on this problem. In the systems approach it is shown that choices made by the individual system builder on the level of system components have influences on the system level. In the actor network approach the concept 'actor' is conceived so broadly as to comprise an electron, an individual engineer as well as an organization. Thus, it is tried to develop a theory which deals with the micro as well as the macro level of analysis. In the SCOT approach the concept 'technological frame' forms the nodal point between micro and macro level. Developments on the micro level (the design of a prototype for example) are shaping a new technological frame which will influence developments on macro level; on the other hand, the technological frame of the engineers incorporates in turn social norms and values and shapes the design process on micro level. None of the three approaches has yet a completely satisfying solution to this problem, but it seems clear that combining the three perspectives and thereby integrating sociological and historical views is more promising than working alone.

Appendix I

The Interdisciplinary Centre for Science and Technology Studies 'De Boerderij' and the Program Philosophy of Science, Technology and Society (WWTS)

In this appendix, first I will sketch the Centre for the Problems of Science and Society 'De Boerderij'. This institute is rather typical in its interdisicplinary organization and research topics, although it is much larger than most other Dutch research groups in this field. Then, I will outline the interdisciplinary Master's degree program 'Philosophy of Science, Technology and Society' (WWTS), which offers the degree 'philosophical engineer'. To provide some background to facilitate the comparison with the Technische Hochschule Darmstadt, I will start with a brief sketch of the University of Twente and then 'zoom-in' to the Department of Philosophy and Social Sciences and subsequently the institute 'De Boerderij'.

The University of Twente

The University of Twente (UT) is a relatively small institution with some 5000 students, 700 academic staff and 2000 non-academic staff. It was founded as a technical university. Today, it includes departments for social sciences as well. However, the emphasis in research and teaching still is on technical and applied social sciences, rather than on the humanities.

The Department of Philosophy and Social Sciences

The Department of Philosophy and Social Sciences (FWMW – Faculteit der Filosofie en der Maatschappijwetenschappen) has a hybrid function within the university. First, it houses the Philosophy of Science, Technology and Society Program (WWTS – Wijsbegeerte van Wetenschap, Techniek en Samenleving) which offers a Master's (Dutch: doctorandus) degree and a Ph.D. (Dutch: doctor). Second, the Department is responsible for 'service teaching' to other departments of the UT. Both aspects will be discussed more extensively later.
The FWMW comprises six sections – philosophy, history, philosophy of science and technology, psychology, linguistics and ergonomics. Each section has, in principle, one full professor, one senior lecturer, 2–4 lecturers and a varying number of research fellows and graduate students.

'De Boerderij' Research Projects

The section Philosophy of Science and Technology, one of the six sections of the Department of Philosophy and Social Sciences, constitutes the Centre for Studies on Problems of Science and Society 'De Boerderij'. It is located in a separate building on the campus of the university. This building is, because of its architectural concept, called 'De Boerderij' (the Farm), lending its name to the research group as well.

The origins of 'De Boerderij' group are, typically, in the first STS stage of the science studies development in the Netherlands. Thus the staff consists of a relatively large number of physicists, chemists, biologists, mathematicians and engineers, supplemented by sociologists, an economist and a political scientist, in total more than 200 researchers and research assistants.

The research program of 'De Boerderij' can be described as resting on three pillars – (1) science and technology studies, (2) peace research and (3) simulation studies and organizational sociology. The following research projects are currently carried out or have recently been completed.

Science and technology studies:

- History of 19th century biology, assessing the fruitfulness of Piaget's genetic epistemology perspective,
- History of the ultra-centrifuge,
- History of the nuclear waste controversy; a comparative study of American and Dutch developments,
- Various studies in the history and sociology of DNA recombinant technology, especially as related to risk analysis, technology assessment and policy issues,
- Comparative study of four historical cases to give a theoretical sociological analysis of the development of technical artefacts,
- Various impact studies and technology assessments.

Peace research:

- Relation between the socio-economic development of Third World countries and military expenditures, especially Kenia, Peru, Indonesia,
- Monitoring Star Wars in relation to European security,
- Various projects on the relation between nuclear energy and nuclear proliferation,
- The effects of nuclear attack on the Netherlands,
- European defense and 'emerging technologies',
- (Recently finished) projects on Electro-Magnetic Pulse and the Patriot weapon system,

- Arms control, technology assessment and political processes,
- Laser fusion and nuclear proliferation.

Simulation research and organizational sociology:

- Development of instruments for social simulation, to be used as research as well as training instruments,
- Theoretical analysis of processes of organization,
- Empirical sociological study of the Dutch science policy system,
- Empirical study of technological innovation processes.

Although, for the sake of clarity, the research projects can be divided into the previous three sets, in practice there is much overlap. And this overlap is deliberately pursued. For example, the work on a sociological theory of the interactions within and between organizations and other social groups (in set 'Simulation research and organizational sociology') is used and further developed in the comparative study of four technical inventions (in set 'Science and technology studies') and other projects in set 'Science and technolgy studies'. This collaboration subsequently led to a project to build a simulation to investigate empirically the process of invention (in set 'Simulation research and organizational sociology'). The relations between the various projects in sets 'Peace research' and 'Science and technology studies' are obvious – laser fusion can be studied as a technological and scientific development, using the perspectives developed in the other projects in the first set; and it can be studied as a potential threat to a world wide control of nuclear proliferation.
Linked to the research program of 'De Boerderij' is the women studies research. The women studies group is located in 'De Boerderij' building and, although formally independent, takes part in many activities of 'De Boerderij' staff. Their research, in so far as it is related to the research program of 'De Boerderij' includes:

- Obstructions for women to enter technological professions. Research on (a) the level of secondary school and (b) university level (finished with two reports),
- 'Masculine' and 'feminine' values in the practice of technological research,
- Implications of the process of automation on women's jobs. The process of 'genderization' of new jobs,
- Dutch female engineers: Where are they and what are they doing?

The Program Philosophy of Science, Technology and Society (WWTS)

The interdisciplinary program Philosophy of Science, Technology and Society (WWTS), provided by the Department of Philosophy and Social Sciences, offers a Master's degree, or rather an engineering degree. The program offers a considerable education in engineering as a basis for the philosophical and social science part of the education. For example, as the first year of the WWTS curriculum students have to choose a first year in one of the engineering sciences of the Twente University. Also during the subsequent three years of the Master's program, considerable attention is paid to this engineering science (some 30 %), bringing the total amount of engineering courses in the program to almost 50 %.

The 'philosophical' half of the program has two parts. The first part is constituted by a set of courses common to all students and the second part contains optional 'variants'. The common part comprises courses in history and philosophy of science, sociology of science and technology, social philosophy, linguistics and psychology. The option part contains six variants: Technology and Developing Countries, Labor Questions and Ergonomics, Safety and Environment, Technology and Knowledge Transfer, Controlling Science and Technology. Each student chooses one variant.

The final step is writing a Master's thesis. I will describe one typical example. This Master's thesis would be titled 'A technology assessment of laser technology' and would focus on the history of laser technology and an assessment of the various application fields and relevant (or potentially relevant) social groups. Questions to be answered are: What types of laser have been developed and in what institutional contexts? What is the relation between research labeled by the actors as 'pure' and research labeled as 'applied'? Selecting one laser type to focus on in the second part of the study, one could then try to identify (potentially) relevant social groups and application domains. Questions to be answered in this second part could be: What meaning do relevant social groups attribute to the different possibilities? What means of control and steering are employed by various groups?

Together with the universities of Amsterdam, Groningen and Limburg, a graduate school Science Dynamics has been founded.

Service Teaching

To the other departments, especially those offering engineering degrees, the Department of Philosophy and Social Sciences is linked through service teaching. Within his/her curriculum, every engineering student has to choose a certain number of non-technical courses. These courses are offered by the various social science departments.

Courses which have been taught recently by 'De Boerderij' staff are: Science – Theory and Practice; Philosophy of Science; Science and Emancipation; Tech-

nology and Gender; Science, Technology and Society; Technology, International Relations and International Law; Technology, War and Peace; Development of Biotechnology and Genetic Engineering; Modern Science and Technology Studies.
The non-technical courses cannot be chosen without constraints. Several 'themes' have been developed to structure the selection of these courses in such a way that engineering students will follow a program of courses which build upon one another in subsequent years, thus enabling a more in-depth discussion of that theme. Themes are, for example, 'history and foundations of science and technology', 'science, technology and society', 'a just society', 'human information technology', 'the functioning of organizations', 'technology and labour'.

Appendix II

Delta Studies at the University of Limburg

At the University of Limburg in Maastricht plans are being developed to establish an interdisciplinary 'arts and sciences program'. In this program, called 'Delta Studies', there is a double emphasis: first on professional training within any of the four Master's programs of the University of Limburg (i. e. medicine, health sciences, law and economics) and second on an interdisicplinary analysis of relations between science, technology and society.
The program is aimed at providing the kind of professional interdisciplinary training which, for example, big multinational companies have been asking. These companies need broadly educated academics who have enough intellectual training to operate on an international level and who have acquired basic scientific skills. These general scientists would then be trained in 'in-house' educational programs by the companies themselves to fit for specific jobs. Until recently, graduates with a degreee of a law school were frequently employed for these purposes, but they lack an experience in natural and social sciences and that is exactly what the 'Delta Studies' program seeks to provide.
The curriculum starts with a first year which has to be done within one of the four departments. Of the subsequent three years, 30% of the curriculum is in the field of the department where the student had his/her first year; a second 30% of the curriculum is provided in the form of courses designed specifically for 'Delta Studies'; the last 30% consists of various skill trainings, an international traineeship and a Master's thesis.
The curriculum is designed around specific themes. The first theme will be 'development of medical sciences and health systems and their legal, economic and ethical consequences'. Elements in this theme are for example: the social

shaping of medical technology, technology assessment and regulation of medical technologies, norms and values related to the specific structure of professional medical behaviour, science dynamics and science policy of medical sciences, economic, legal and ethical implications of information technology in medical practice. The second theme will be 'long-term developments in politics, law and economics related to technological development, especially in international perspective'. Elements in this second theme are: variation in and cultural background of political, economic and legal systems, social and ethical impact of technology, technological forecasting and technology policy, cultural traditions and technological trajectories. The third theme is 'professions and the emergence of expert systems'. Elements here are: cognitive basis of knowledge systems, epistemological problems of expert systems, formalizing fuzzy systems, ethical and legal implications of information technology, foundational problems of decision theory.
Additionally, much emphasis throughout the curriculum will be on the training of specific skills: writing essays and reports, using information technology, presentation of research results, working in an interdisciplinary group, foreign languages.

Notes

1 T. S. Kuhn, *The Structure of Scientific Revolutions*, 2nd edition (Chicago, 1962).

2 See for example G. Böhme, W. van den Daele und W. Krohn (Hrsg.), *Experimentelle Philosophie. Ursprünge autonomer Wissenschaftsentwicklung* (Frankfurt a. M., 1977); G. Böhme, W. van den Daele, R. Hohlfeld W. Krohn, W. Schäfer und T. Spengler (Hrsg.), *Starnberger Studien I. Die Gesellschaftliche Orientierung des Wissenschaftlichen Fortschritts* (Frankfurt a. M., 1979); W. van den Daele, W. Krohn und P. Weingart (Hrsg.), *Geplante Forschung. Vergleichende Studien über den Einfluß politischer Programme auf die Wissenschaftsentwicklung* (Frankfurt a. M., 1979).

3 Large parts of this section have been published previously in T. J. Pinch and W. E. Bijker, 'The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other', *Social Studies of Science*, Vol. 14 (1984), 399–441.

4 See R. D. Whitley, 'Black Boxism and the Sociology of Science: A Discussion of the Major Developments in the Field', in P. Halmos (ed.), *The Sociology of Science, Sociological Review Monograph*, No. 18 (Keele, 1972), 61–92.

5 E. Layton, 'Conditions of Technological Development', in I. Spiegel-Rösing and D. de Solla Price (eds.), *Science, Technology, and Society* (London and Beverly Hills, 1977), 198.

6 See, for example, N. Rosenberg, *Inside the black box. Technology and economics* (Cambridge, 1982).

7 J. M. Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge, Ma., 1985).

8 Eugene Ferguson, 'Toward a Discipline of the History of Technology', *Technology and Culture*, Vol. 15 (1974), 13–30, 19.

9 M. Kaufmann, *The First Century of Plastics; Celluloid and its Sequel* (London, 1963), 61.

10 L. H. Baekeland, 'The Synthesis, Constitution, and Uses of Bakelite', *Industrial and Engineering Chemistry*, Vol. 1 (1909), 149–61; and L. H. Baekeland, 'On Soluble, Fusible, Resinous Condensation Products of Phenols and Formaldehyde', *Journal of Industrial and Engineering Chemistry*, Vol. 1 (1909), 545–9.

11 Manuals describing resinous materials do mention Bakelite, but not with the amount of attention which, retrospectively, we would think to be justified. Professor Max Bottler, for example, devotes only one page to Bakelite in his 228-page book on resins and the resin industry: M. Bottler, *Harze und Harzindustrie* (Leipzig, 1924). Even when Bottler concentrates, in another book, on the *synthetic* resinous materials, Bakelite does not receive an indisputable 'first place'. Only half of the book is devoted to phenol/formaldehyde condensation products, and roughly half of the latter is devoted to Bakelite. M. Bottler, *Über Herstellung und Eigenschaften von Kunstharzen und deren Verwendung in der Lack- und Firnisindustrie zu elektrotechnischen und industriellen Zwecken* (München, 1919). See also A. R. Matthis, *Insulating Varnishes in Electrotechnics* (London, approximately 1920).

12 W. Haynes, *American Chemical Industry*, Vol. 2 (New York, 1954), esp. 137–8.

13 Staudenmaier, op. cit. note 7. See also Thomas P. Hughes, 'Emerging Themes in the History of Technology', *Technology and Culture*, Vol. 20 (1979), 697–711.

14 See, for example, Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore, 1980); Thomas P. Hughes, *Networks of Power: Electrification in Western Society: 1880–1930* (Baltimore, 1983).

15 See, for example, David F. Noble, Forces of Production: A Social History of Industrial Automation (New York, 1984); Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, N.Y., and London, 1977); and W. Lazonick, 'Industrial Relations and Technical Change: the Case of the Self-Acting Mule', *Cambridge Journal of Economics*, Vol. 3 (1979), 231–62.

16 There is an American tradition in the sociology of technology. See, for example, S. G. Gilfillan, *The Sociology of Invention* (Cambridge, Ma., 1935); W. F. Ogburn, *The Social Effects of Aviation* (Boston, Ma., 1945); W. F. Ogburn and F. Meyers Nimkoff, *Technology and the Changing Family* (Boston, Ma., 1955). See also R. Westrum, 'What happened to the Old Sociology of Technology?', paper presented to th Eighth Annual Meeting of the Society for Social Studies of Science (Blacksburg, Virginia: November 3–6, 1983). A fairly comprehensive view of the present state of the art in German sociology of technology can be obtained from R. Jokisch (ed.), *Techniksoziologie* (Frankfurt a. M., 1982). Several studies in the sociology of technology which attempt to break with the traditional approach can be found in W. Krohn, E. T. Layton and P. Weingart (eds.), *The Dynamics of Science and Technology, Sociology of the Sciences Yearbook*, Vol. 2 (Dordrecht and Boston, Ma., 1978).

17 R. Johnston, 'The Internal Structure of Technology', in P. Halmos (ed.), *The Sociology of Science, Sociological Review Monograph*, No. 18 (Keele, 1972), 117–30.

18 G. Dosi, 'Technological Paradigms and Technological Trajectories: A suggested interpretation of the determinants and directions of technical change', *Research Policy*,- Vol. 11 (1982), 147–62. Dosi uses the concept of 'technological trajectory', developed by R. R. Nelson, and S. G. Winter, 'In Search of a Useful Theory of Innovation', *Research Policy*, Vol. 6 (1977), 36–76.

19 Other approaches to technology based on Kuhn's idea of the community structure of science can be found in Constant, op. cit. note 14, and P. Weingart, ‚Strukturen technologischen Wandels. Zu einer soziologischen Analyse der Technik', in Jokisch (ed.), op. cit. note 16, 112–41.

20 Two news reports on the workshop have been published: G. H. de Vries, 'International Workshop on New Developments in the Social Study of Technology (Twente University of Technology, Netherlands, 5–7 July 1984) – A Personal Report', *EASST Newsletter*, Vol. 3 (november 1984), 12–8; J. Law, 'International Workshop on New Developments in the Social Studies of Technology', *4 S Review*, Vol. 2 (winter 1984), 9–13. John Law concludes: 'Perhaps, in retrospect, we may look back to it as the place where the social study of technology first became a recognizable field rather than a set of individuals'.

21 W. E. Bijker, Th. P. Hughes and T. J. Pinch (eds.), *The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology* (MIT Press: Cambridge, Ma., 1987).

22 Bruno Latour, *Science in Action* (Milton Keynes, 1986); Boelie Elzen, 'Two Ultra-Centrifuges. A Comparative Study of the Social Construction of Artefacts', *Social Studies of Science*, Vol. 16 (1986), 621–62; Thomas P. Hughes, 'The Seamless Web: Technology, Science, Etcetera, Etcetera', *Social Studies of Science*, Vol. 16 (1986), 281–92; Donald MacKenzie and Graham Spinardi, 'Weapons Technology in Social and Historical Perspective: U.S. Navy Fleet Missile Guidance from Polaris to Trident', forthcoming in *Social Studies of Science*.

23 See for a more complete introduction Th. P. Hughes, 'The Evolution of Large Technological Systems', in: Bijker, Hughes, Pinch (eds.), op. cit. note 21, 51–82; Th. P. Hughes, *Networks of Power. Electrification in Western Society, 1880–1930* (Baltimore, 1983).

24 See for a more complete introduction M. Callon, 'Society in the Making: The Study of Technology as a Tool for Sociological Analysis' and J. Law, 'Technology and Heterogeneous Engineering: The Case of the Portuguese Expansion', both in Bijker, Hughes, Pinch (eds.), op. cit. note 21.

25 See, for example, M. Callon, J. Law and A. Rip (eds.), *Mapping the Dynamics of Science and Technology* (London, 1986). I will not further discuss co-word analysis in this paper.

26 For a more extensive presentation, see T. J. Pinch and W. E. Bijker, 'The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other', and W. E. Bijker, 'The Social Construction of Bakelite. Towards a Theory of Invention', both in Bijker, Hughes, Pinch (eds.), op. cit. note 21.

27 Meadows, cited in J. Woodforde, *The Story of the Bicycle* (London, 1970), 49–50.
28 Cited in Woodforde, op. cit. note 27, 122.
29 'The Stanley Exhibition of Cycles', *The Engineer*, Vol. 69 (7 February 1890), 107–08.
30 This is illustrated in detail in W. E. Bijker, 'Understanding the Social Construction of Fluorescent Lighting: No Role for Economic Power', paper presented to the Four Society Meeting, Pittsburgh, Pa., 23–26 October 1986.
31 J. B. Dunlop, 'An improvement in Tyres of Wheels for Bicycles, Tricycles, or Road Cars', *Briths Patent No. 10607* (date of application: 23 July 1888).
32 'The Stanley Exhibition ...', op. cit. note 29, 107.
33 W. Grew, *The Cycle Industry, its Origin, History and Latest Developments* (London, 1921), 8.
34 Woodforde, op. cit. note 27, 89.
35 E. W. Constant, 'Scientific Theory and Technological Testability: Science, Dynamometers, and Water Turbines in the 19th Century', *Technology and Culture*, Vol. 24 (1983), 183–98. See also D. MacKenzie, 'From Kwajalein to Armageddon? Testing and the social construction of missile accuracy', in D. Gooding, T. J. Pinch and S. Schaffer (eds.), *The Uses of Experiment* (Cambridge, Ma., 1987) forthcoming.
36 See Bijker, op. cit. note 26. Here I have sketched a typology of different sorts of technological change using the concepts 'technological frame' and 'inclusion'.
37 D. MacKenzie, 'Missile Accuracy: A Case Study in the Social Processes of Technological Change', in Bijker, Hughes, Pinch (eds.), op. cit. note 21.

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